Performance of $LaBr_3$ Detectors for Fresh Fallout Response (PERLAD)

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NKS seminar Nordic Nuclear Safety: Research, Operations and Beyond, Stockholm, 24-25 May 2022

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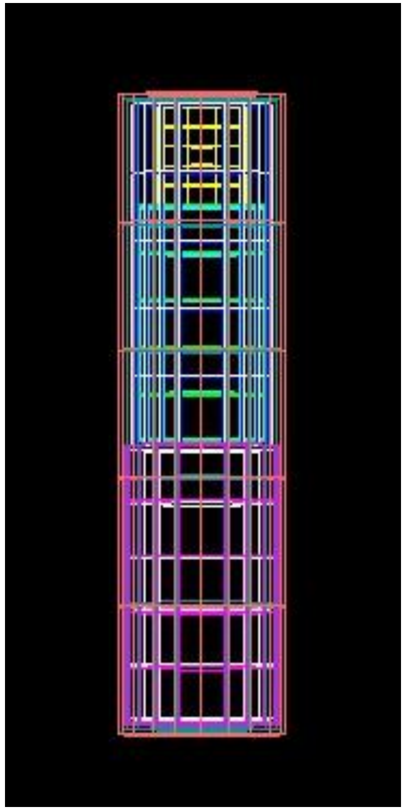
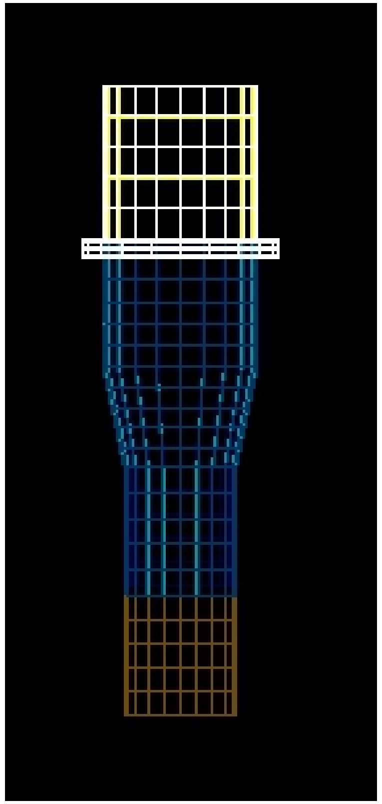
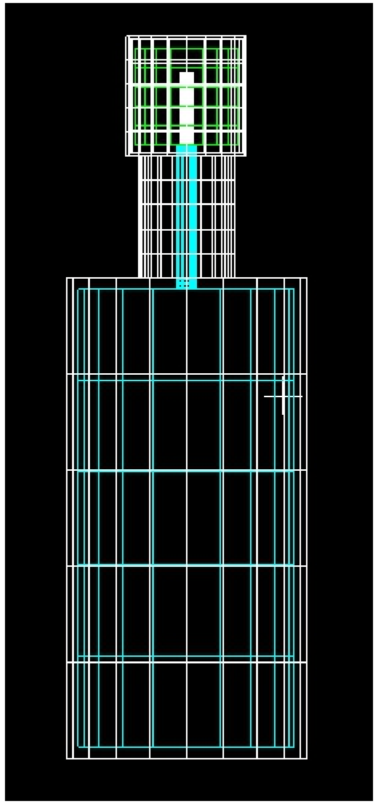
Detectors



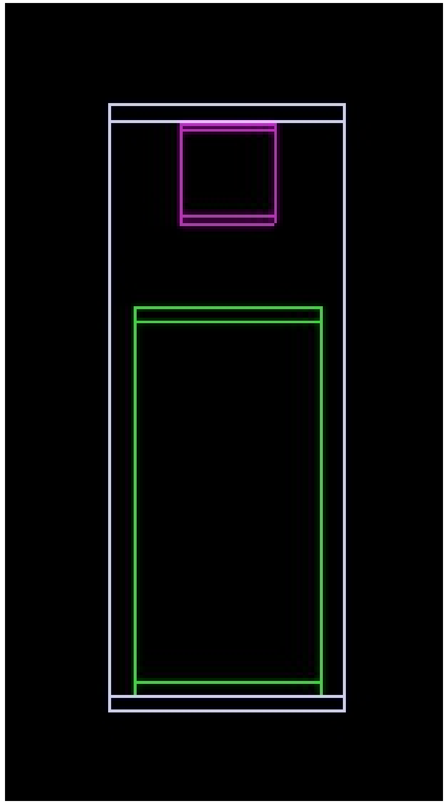
Good resolution
No cooling
Small size
Not bad efficiency
Reasonable price



Poor resolution
No cooling
Small size
Good efficiency
Reasonable price



Great resolution
Needs cooling
Awkward size
Not great efficiency
Expensive



Good resolution
No cooling
Very small size
Terrible efficiency
Expensive

Context

Direct quantitative/qualitative measurement of airborne contaminants/fallout by $LaBr_3$ detectors:

- Cloud geometry
- Ground geometry

Problems with the above:

- Efficiency calibration for cloud shine geometry
- Efficiency calibration for very large ground areas
- Qualitative – how does $LaBr_3$ cope with fallout type spectra?
- Separation of cloud and ground signals

DSA Norwegian Radiation and Nuclear Safety Authority

Approaches

Efficiency calibration – two obvious candidate methods:

- Analytical functions
- Monte Carlo simulations

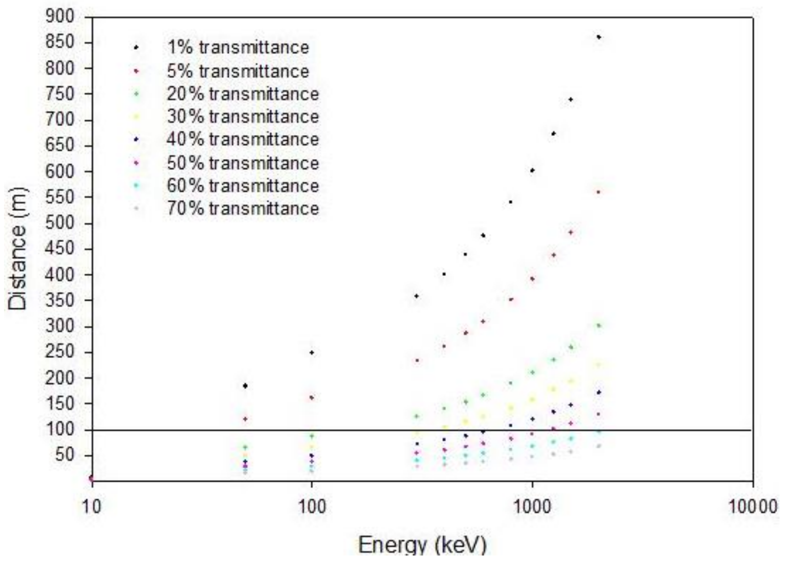
Some data from an analytical approach was available for the $LaBr_3$ detectors.

The Monte Carlo approach is at first glance relatively simple – the geometry is not very complex.

The primary problem is the size of the geometry – as photons can travel long distances in air, the geometry modelled has to be very large.

Related to the above, the amount of activity to be simulated – the «*number of histories*» - becomes very large resulting in impracticable simulation times* (weeks or months)

**for the workstations available to the project*



	Bq/m³	Bq in total volume (750 m radius)
^{131}I	3046	2,56811E+12
^{132}I	2937	2,47621E+12
^{133}I	2443	2,05971E+12
^{134}Cs	321	2,70638E+11
^{136}Cs	73	6,2E+10
^{137}Cs	251	2,1162E+11
^{103}Ru	298	2,51246E+11
^{127}Sb	218	1,83798E+11
^{140}Ba	914	7,70601E+11
^{140}La	209	1,7621E+11
^{141}Ce	66	5,5645E+10
^{91}Y	376	3,17009E+11
^{91}Sr	58	4,89E+10
^{95}Zr	80	6,7448E+10
^{95}Nb	409	3,44831E+11
^{131m}Te	202	1,70308E+11
^{132}Te	2850	2,40286E+12
^{131}Te	45	3,79E+10
^{91m}Y	37	3,1195E+10
^{133}Xe	27	2,27639E+10
^{135}Xe	193	1,6272E+11

DSA

Direktoratet for strålevern og atomsikkerhe

Approaches

A series of air-filled hemispheres were constructed which functioned as uniform sources of monoenergetic photons where the radius of the hemisphere corresponded to the 95% transmission distance of the photon.

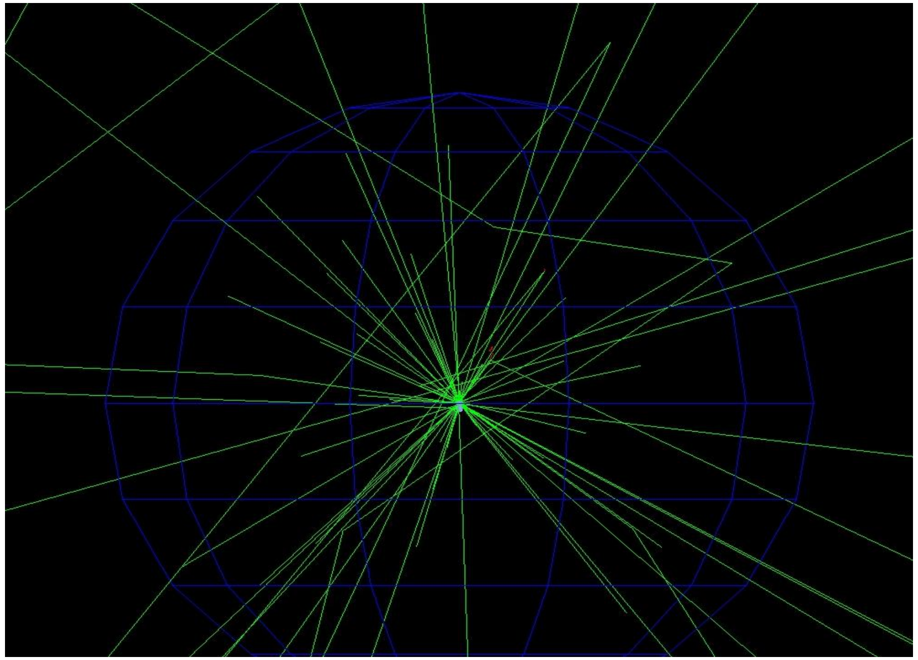
Only photons that would interact with a voume around the detector would be followed – this facilitates estimation of the full energy photopeak only.

The activity present in the hemisphere was then determined based on a simulation period of approximately two weeks.

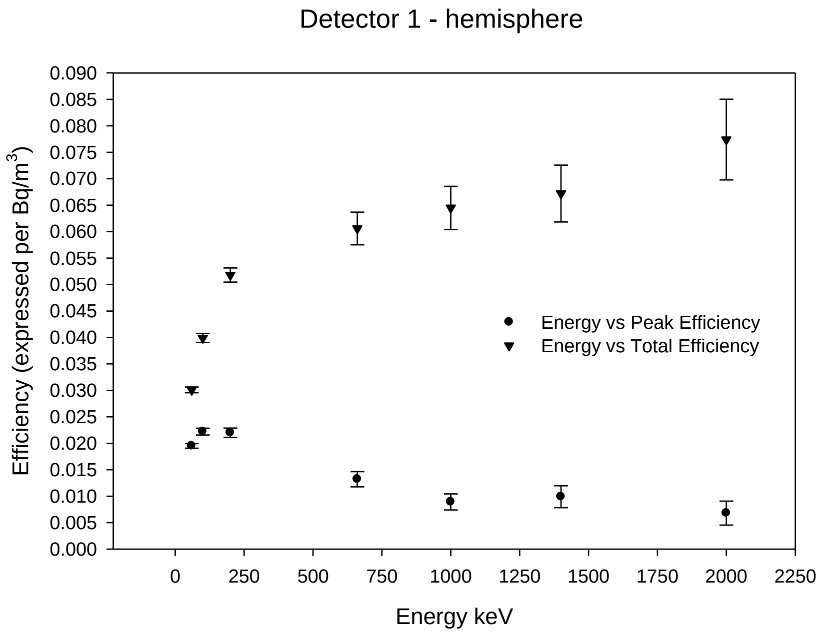
This was then performed for all the energies and for all of the detectors.
to obtain an estimate of the efficiencies for the cloud shine geometry.

All simulations were conducted with GEANT4 - physics packages QGSP_BIC_HP plus Radioactive Decay

keV	Hemisphere radius m	Total volume m^3	Activity per m^3
60	204	1.78E+07	1000
100	250	3.27E07	543.34
200	310	6.24E+07	284.97
661	510	2.78E+08	64.0
1000	602	4.57E+08	38.91
1400	715	7.66E+08	23.23
2000	860	1.33E+09	13.35



Outcomes



The simulations generate a series of efficiency curves for each detector typical of any other geometry.

Two possible ways of assessing outcomes: relative to results produced by other calculations and relative to some comparison between the model and reality.

Relative to results computed by other means – the results are not so deviant. The computational method omits certain aspects of possible relevance – angular dependancies, detector height, contributions of near detector activity etc.

In addition, the Monte Carlo method has its own vulnerabilities related to the quality of the model used to represent the detector.

Energy keV	Radius m	Bq/m^3	Peak eff. Sim. (counts/(Bq/m^3))	Peak. eff. Comp.	Rel. diff (%)
60	204	1000	**0.0152**	0.0186	18
100	250	543.34	**0.0197**	0.0242	19
200	310	284.97	**0.0234**	0.0281	17
661	510	64.0	**0.0130**	0.0155	16
1000	602	38.91	**0.0100**	0.0124	19
1400	715	23.23		0.0109	
2000	860	13.35	**0.0067**	0.0095	29

Models

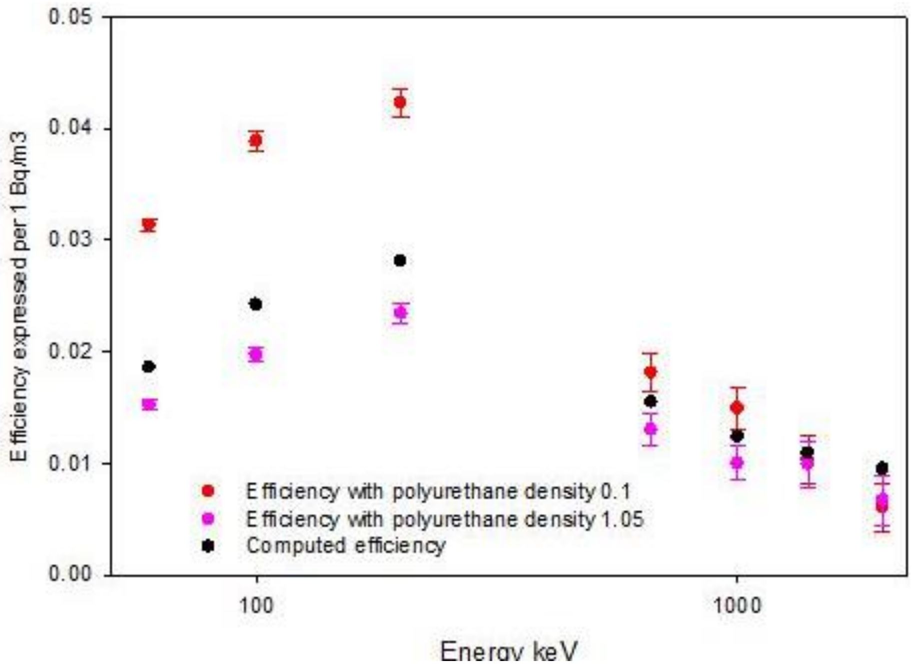
The problem of models in simulation of detectors is well known.

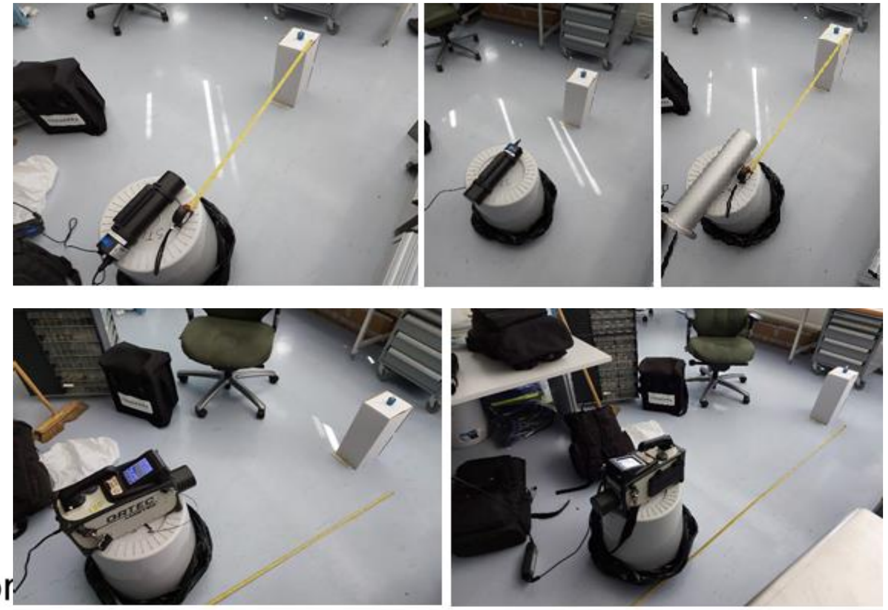
The information available from manufacturers is often less than ideal.

For detectors designed for outdoor use which may have weather shields or various types of «*ruggedisation*» – the problem is worse.

To test how the models were performing – a series of experiments were conducted comparing empirical data to the simulated data.

In general – for sources in front of the detector, simulation to an acceptable degree is possible. For sources behind the detectors – simulation to an acceptable degree is not possible. The problem being worse the more «stuff» there is behind the crystal (HPGe type systems being very problematic).





Nuclide	Act. (MBq)	Dist. (m)	E (keV)	Orient.	Livetime (s)	Area Simulated	CPS Simulated	Area Actual	CPS Actual
Am-241 as «pure point» source	10.7	1	60	Front	260	74526 ± 1484 *	286	23744	89
				WS	269	75218 ± 270*	279	22181	83
				Back	892	?????	????	1131.6	1.27
Am-241 as	10.7	1	60	Front	260	69410	266	23744	89
aluminium				WS	269	81071	301	22181	83
point source				Back	892	??????	????	1131.6	1.27
Co-57 as volume source	10.4	1.5	122	Front	372	92490	248	80177	216
				WS	375	91488	244	87220	237
				Back	428	97	0.22	8145	19.0
			136	Front	372	11634	31.3	4144	11.1
				Back	428	47	0.10	330	0.77
Co-57 as a	10.4	1.5	122	Front	372	30925	265	80177	216
thin surface				WS	375	97679	260	87220	237
source				Back	428	327	0.76	8145	19.0
			136	Front	372	3684	33.3	4144	11.1
				Back	428	121	0.28	330	0.77
Cs-137	8.9	2	662	Front	156	6940 ± 138*	44.7	7055	45.2
				WS	248	10787	43.5	11096	44.7
				Back	280	4314	15.40	4847	17.3
Co-60	3.5	2	1173	Front	503	5792 ± 98*	11.6	5373	10.7
				WS	491	5309	10.81	5850	11.9
				Back	500	2612	5.22	2757	5.5
			1332	Front	503	5091 ± 64*	10.28	4894	9.7
				WS	491	4674	9.51	5073	10.3
				Back	500	2482	4.96	2602	5.2

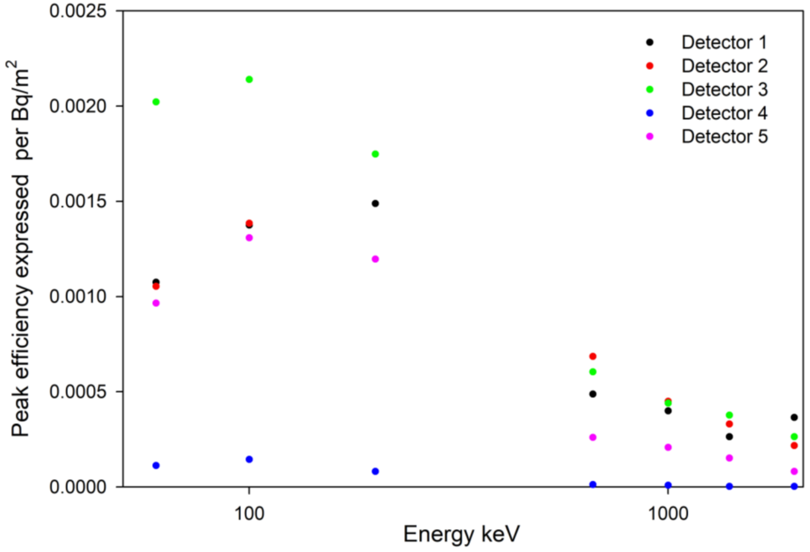
Surface deposistion

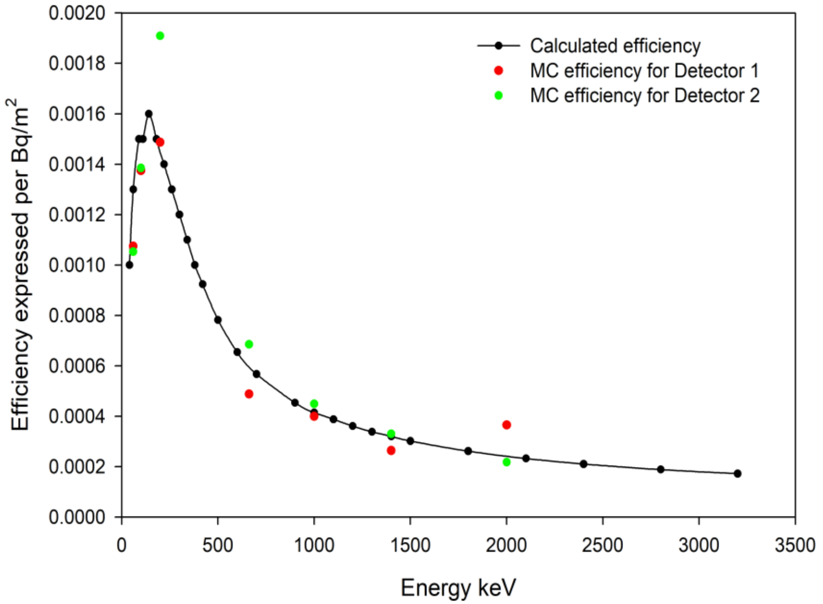
Similar approach adopted for the ground deposition.

Circular disks with a soil composition were constructed of radii corresponding to the 95% transmission for the energy concerned.

Spectra were then recorded for each detector type using the same restrictions as for the cloud shine scenario.

Results for MC calculations for $LaBr_3$ detectors comparable with results yielded from calculations.





Qualitative

Two scenarios presented – cloud shine and deposition.

Data used for isotopes and activity levels from Johansson et al., 2019.

For cloud shine – 2 assemblages devised:

- Cloud activity 5 – 6 hours after release
- Cloud activity 20-21 hours after release

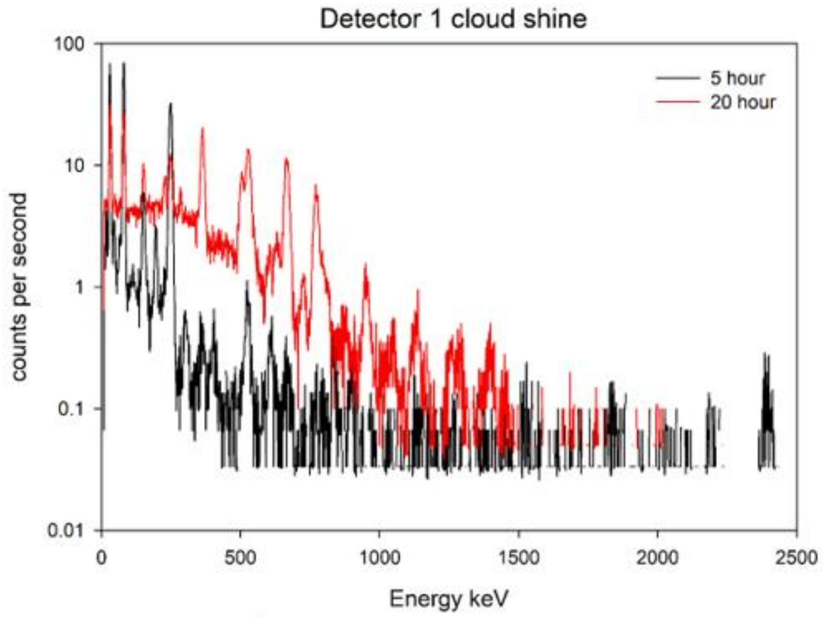
For deposition – 3 assemblages devised:

- After 3 days
- After 7 days
- After 30 days

Johansson, J., Kock, P., Boson, J., Karlsson, S., Isaksson, P., Lindgren, J., Tengborn, E., Blixt Buhr, A.M., Bäverstam, U. 2019. Review of Swedish emergency planning zones and distances, Appendix 3, Report number: 2017:27e ISSN: 2000-0456. 91 p.

Isotope	Bq/m³	Hemisphere volume m³	Total activity Bq
Xe-133	2.8E+04	718377.52	2.00643E+10
Xe-135	1.1E+04	718377.52	8.22183E+09
Kr-88	2.3E+03	718377.52	1.62425E+09
Rb-88	1.6E+03	718377.52	1.18329E+09
Kr-85m	1.4E+03	718377.52	9.95671E+08
Xe-133m	9.0E+02	718377.52	6.43666E+08
Xe-135m	6.4E+02	718377.52	4.60121E+08
Kr-87	2.7E+02	718377.52	1.91340E+08
I-133	1.7E+02	718377.52	1.22211E+08
I-132	1.4E+02	718377.52	9.90643E+07
Te-132	1.3E+02	718377.52	9.65499E+07
I-135	1.0E+02	718377.52	7.39210E+07
I-131	9.7E+01	718377.52	6.94174E+07
Cs-134	2.6E+01	718377.52	1.87066E+07
Mo-99	2.2E+01	718377.52	1.59157E+07
Ba-137m	1.8E+01	718377.52	1.26973E+07
Te-131m	1.7E+01	718377.52	1.21693E+07
I-134	6.2E+00	718377.52	4.46242E+06
Cs-136	5.9E+00	718377.52	4.22406E+06

Table 6. Isotopes and activities for the 5-6 hour cloud scenario.



5 hour and 20 hour cloud shine spectra for Detector 1.

Qualitative

In general – there is no problem in adapting analytical routines for HPGe detectors.

Results – irrespective of which method for efficiency calculation is used – are probably more than adequate for emergency preparedness uses.

Nuclide	Deposition density (Simulated) (kBq/m²)	Deposition density (Detector 1) (kBq/m²)	Deposition density (Detector 2) (kBq/m²)
I-131	16.202	13.98	18.83
I-132	5.945	4.01	6.0
Te-132	5.764	5.03	7.6
Mo-99	5.555	5.12	5.12

Table 11. 3-day ground deposition results

Nuclide	Deposition density (Simulated) (kBq/m²)	Deposition density (Detector 1) (kBq/m²)	Deposition density (Detector 2) (kBq/m²)
Cs-134	5.060	3.72	5.15
Cs-137	3.520	2.54	3.36
I-131	2.855	2.76	3.25
Te-129m	460	-	-

Table 13. 30-day ground deposition results

Nuclide	Activity conc. (Simulated) (kBq/m³)	Activity conc. (Detector 1) (kBq/m³)	Activity conc. (Detector 2) (kBq/m³)
I-132	11.71	7.4	7.07
I-133	11.33	8.01	7.04
I-131	10.14	8.07	6.16
Xe-133	9.57	9.49	7.09

Table 15. 20 hour cloud results

Separation of ground and cloud

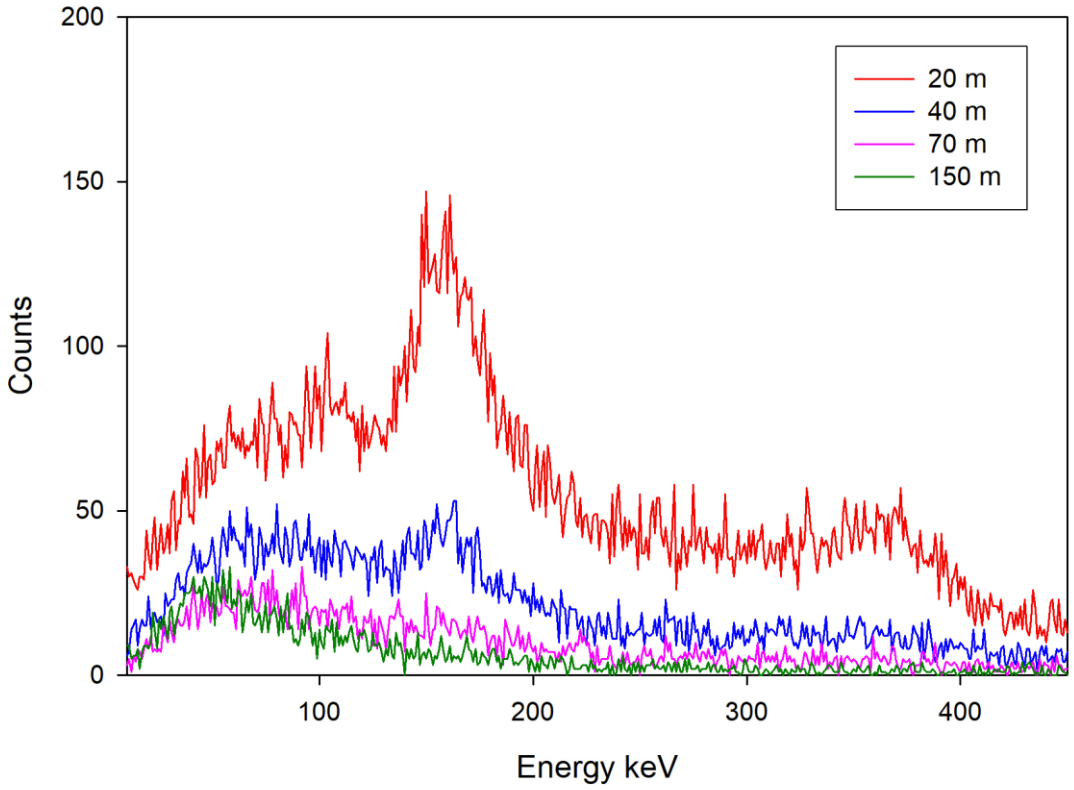
Differentiation of signals arising from cloud contamination from those generated by deposition on the ground.

If achievable - most probably based on the lower energy region.

Requires simulation where there are no restrictions applied – all histories must be followed to ensure scattered radiation is included.

Very significant increase in computational time required.

Subsequent work indicates potential problems in such an approach.



Lessons learned

- I really need better/more computers

- Monte Carlo is probably a reasonable way to estimate efficiencies for semi-infinite cloud geometries or long range flat plane geometries for energies over 200 keV

- Given the difficulty in modelling ancilliary assemblies in the detector module – its debateable whether or not there is anything to be gained by Monte Carlo over simpler methods. Especially for «ruggedized» detectors.

- It is probably improbable that there is an acceptable way of separating out which signals come from the ground and which come from the cloud by simply looking at spectral details
- Of all the detector types – $LaBr_3$ is probably the one best suited to these types of measurements

Questions?